Tillage and fallow effects on selected soil quality characteristics of former conservation reserve program sites

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ABSTRACT: Tillage and fallow have been suggested as management options for converting Conservation Reserve Program (CRP) areas to cropland. This study was conducted to measure selected soil quality characteristics of former CRP sites in Mississippi, Nebraska, and South Dakota that were tilled and then left fallow for 21 or 22 months. Soil samples from depth intervals of 0–7.6 cm and 0–30.5 cm were collected for laboratory assessment of the following soil quality indicators: bulk density, EC, pH, total C, organic C, total N, NO_3–N, NH_4–N, PO_4–P, biomass C, biomass N, anaerobic NH_4–N, lab respiration 0–10 days, and lab respiration 10–20 days. When compared to undisturbed CRP, increased NO_3–N values on the tillage and fallow plots suggest that under the extreme conditions employed in this study, organic residues were being mineralized. As a result, significant reductions in organic C and total N were found at the 0–7.6 cm depth on each of the fallow plots. Thus, to reduce soil quality degradation, use of minimum-till or no-till management systems may be best suited for CRP areas which are converted to cropland.

Keywords: Conservation benefits, grassland, land management, soil organic matter, soil properties

Soil structure has been found to improve when cultivated land is put into grass (Lindstrom et al. 1994). The perennial grass cover established under the CRP at selected locations within the Great Plains has also resulted in significant increases in soil organic C compared to cropland conditions (Gebhart et al. 1994). Staben et al. (1997) reported that C mineralization potentials and C pools of fields placed in the CRP were improved after four to seven years, compared with their previous management in a wheat (Triticum aestivum L) fallow rotation. Several soil quality indicators measured by Karlen et al. (1999) in a multi state project were enhanced by sowing perennial grass into highly erodible cropland.

When CRP areas become eligible for release, many land managers who return their land to crop production will be concerned about adopting procedures that will help to maintain conservation benefits derived during the CRP. Because the CRP was established to help stabilize highly erodible soils, returning these areas to crop production without proper conservation measures could have detrimental effects on long term soil productivity (Young and Osborn 1990).

Tillage and over-winter fallowing of a former CRP site in northern Mississippi caused a degradation in soil quality resulting from the decomposition of biological nutrient reserves (Gilley and Doran 1997). Conversion of a CRP area in southwestern Oklahoma to the production of winter wheat resulted in significant reductions in biological nutrient reserves and degradation of soil quality (Gilley et al. 1997a). The beneficial soil properties related to water runoff and soil erosion developed during sod were found to rapidly decline with tillage (Lindstrom et al. 1998).

Aguilar et al. (1988), Bauer and Black (1981), and Zhang et al. (1988) found the organic carbon content of rangeland soils was reduced substantially as a result of long term cultivation. Mann (1986) reported that the greatest rates of change occurred in the first 20 years of cultivation. Bowman et al. (1990) found that when compared with 60 years of cultivation, about half the loss of organic C occurred during the first three years of crop production on a sandy loam soil. Some of the reduction in organic C at the 0–7.6 cm depth may be caused by mixing of the surface and subsurface soil with tillage (Reeder et al. 1998).

In this study, tillage and fallow effects on soil quality characteristics of three soils were measured over a period of 21 or 22 months. Each of the soils, which are considered to be of regional or national importance, were located on uniform slopes having relatively homogeneous soil characteristics.

Study Sites

Grenada site. The Grenada site has a slope gradient varying from 5.4–7.1% and is located approximately 6 km east of Como, Mississippi. The Grenada series (fine-silty, mixed, active thermic Glossic Fragiudalf) consists of moderately well drained soils that have a fragipan. These soils formed in loessal material on uplands and terraces. The texture on the tilled portion of the study area was 16% sand, 61% silt, and 23% clay. Prior to CRP conversion, corn (*Zea mays* L) was grown at this location. The study site was seeded to tall fescue (Festuca arundinacea Schreb) after being placed in the CRP in the fall of 1987.

After having been in the CRP for almost seven years, the Grenada soil was disked to a depth of approximately 8 cm in the summer of 1994 to kill and partially incorporate the grass cover into the soil. Total aboveground biomass prior to tillage was 4.3 Mg ha^{-1}. Vegetative cover had been burned the previous spring to enhance regrowth which could have contributed to the relatively small biomass measurements.

Annual precipitation at this location averages 1450 mm and the mean annual temperature is 16° C ranging from 10° C in January to 33° C in July. The average frost-free growing season is 205 days, extending from April through October.

Hersh site. The Hersh site, which was located approximately 18 km northeast of Ord, Nebraska, had a slope gradient which varied from 5.4–6.3%. The Hersh series (coarse-loamy, mixed, nonacid, mesic Typic Ustorthent) consists of deep, well drained, moderately rapidly permeable soils that formed in mixed sandy and loamy aeolian materials on uplands and stream terraces. The texture on the tilled portion of the study area was 76% sand, 15% silt, and 9% clay. Corn was grown at this location prior to CRP conversion.

The study site was seeded to a mixture of big bluestem (*Andropogon gerardii Vit.*), indiangrass [*Sorghastrum nutans* (L) Nash], little bluestem [*Schizachyrium scoparium* (Michaux) Nash], side-oats grama [*Bouteloua curtipendula* (Michaux) Torrey], and switchgrass (*Panicum virgatum* L) in the fall of 1987. After approximately six years in the CRP, the Hersh soil was moldboard plowed to a depth of approxi-

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mately 18 cm in the summer of 1994 and then disked to a depth of approximately 8 cm. At the time of tillage, total aboveground biomass was 19.3 Mg ha^{-1}.

Annual precipitation at this location averages 605 mm and the mean annual temperature is 10° C ranging from – 6° C in January to 24° C in July. The average frost-free growing season is 151 days, extending from May through October.

Pierre site. The Pierre site, which was located approximately 7 km northeast of Quinn, South Dakota, had a slope gradient that varied from 6.3–7.5%. The Pierre series (fine, smectitic, mesic Aridic Haplustert) consists of well drained soils on uplands that formed from clay shale. The texture on the tilled portion of the study area was 16% sand, 42% silt, and 42% clay. Prior to CRP conversion, wheat (*Triticum aestivum* L) was grown at this location.

The study site was seeded to a mixture of alfalfa (*Medicago sativa* L) intermediate wheatgrass [*Elytrigia intermedia* (Host) Nevski], and western wheatgrass [*Elymus smithii* (Rydb.) Gould] in the fall of 1987. After having been in the CRP for approximately six years, the Pierre soil was disked to a depth of approximately 8 cm in the summer of 1994. Total aboveground biomass at time of disking was 18.8 Mg ha^{-1}.

Annual precipitation at this study site averages 386 mm and the mean annual temperature is 8° C, ranging from -8° C in January to 24° C in July. The average frost free growing season is 125 days, extending from May through September.

Soil Quality Characteristics

Selected soil quality tests were initially conducted soon after disking. Promoeton was then applied to each of the study areas for season long control of annual and perennial weeds. Each of the study sites were rototilled to a depth of approximately 13 cm before the first and second year samples were collected. Soil quality evaluations were also conducted on adjacent undisturbed CRP sites.

The rototill operation was selected as a tillage method which could be uniformly and easily applied to the different geographic locations. Rototilling would be expected to break up the organic matter and mix it with the soil, increasing the rate of decomposition. Thus, the decomposition rate would probably be much higher with this system than with a regular disking or plowing operation. Although the chemical properties may not be affected, physical properties, including soil aggregation, water infiltration, and bulk density, would be influenced by rototilling. It should be emphasized that the bulk density measurements obtained following rototilling represent an unconsolidated condition.

Basic indicators of soil quality as described by Doran and Parkin (1994, 1996), were used to evaluate the experimental sites. Soil samples from depth intervals of 0–7.6 cm and 0–30.5 cm were collected for characterization and laboratory assessment of soil quality by compositing five randomly sampled 1.9 cm diameter cores from upper, middle, and lower slope positions. Tillage and fallow induced changes in selected soil quality parameters may have occurred below the 0–30.5 cm depth, especially at the end of the study. However, the predominate variations in soil quality characteristics would be expected to occur in the upper soil profile. Samples which were obtained immediately after tillage and before the occurrence of rainfall were stored under ice in an insulated chest during transport to the laboratory for processing.

Moist soil samples were passed through a 4.75 mm sieve for analyses of microbial biomass C and N by the chloroform fumigation/incubation procedure (Rice et al. 1996) or for potentially mineralizable N by the anaerobic incubation method (Drinkwater et al. 1996). Samples were passed through a 2 mm sieve for analysis of 2M KCl extractable mineral N (NO_3–N and NH_4–N) (Allan and Killorn 1996), total C and N by dry combustion (Schepers et al. 1989), carbonate C by calcimeter, organic C by difference, Bray and Kurtz extractable P (Bray and Kurtz 1945), and particle size analysis by the hydrometer method (Gee and Bauder 1986). Gravimetric data were converted to a volumetric basis using field measured soil bulk density that enabled conversion of measurements to units needed for meaningful interpretation of soil quality conditions (Doran and Parkin 1996).

To compare soil quality measurements obtained under CRP and fallow conditions (Tables 1, 2, and 3), analysis of variance was performed considering sampling times as repeated measures using PROC MIXED in SAS (Littell et al. 1996) (Tables 4 and 5). A probability level ≤ 0.05 was considered significant. Analysis of variance was also used to compare the soil quality parameters obtained under fallow conditions (Tables 6, 7, and 8). Least-significant-differences (LSD) procedures were employed for mean separation at $p \leq 0.05$ (Steel and Torrie 1980).

Results

Laboratory soil quality measurements obtained under fallow and CRP conditions for the Grenada, Hersh, and Pierre soils are shown in Tables 1, 2, and 3, re-

Table 1. Soil quality measurements under tillage and fallow, and undisturbed CRP conditions for selected dates at the 0-7.6 and 0-30.5 cm depth of the Grenada soil.

Soil Quality Indicator	0–7.6 cm Days Following Initial Tillage				0–30.5 cm Days Following Initial Tillage			
	Fallow 275	CRP 275	Fallow 632	CRP 632	Fallow 275	CRP 275	Fallow 632	CRP 632
Bulk Density* (g cm^{-1})	1.23	1.34	0.96	1.28	1.55	1.40	1.51	1.48
EC (dS m^{-1})	0.22	0.02	0.13	0.03	0.07	0.01	0.09	0.03
pH	4.8	5.4	4.8	5.3	4.8	4.8	4.6	4.9
Total C (kg C ha^{-1} depth)†	10000	14200	7300	12800	22200	30700	23400	27600
Organic C (kg C ha^{-1} depth)	10000	14200	7300	12800	22200	30700	23400	27600
Total N (kg N ha^{-1} depth)	1130	1430	830	1290	3290	3920	3230	3480
NO_3-N (kg N ha^{-1} depth)	25	0.1	31	0.1	38	0.3	67	1.1
NH_4-N (kg N ha^{-1} depth)	2.7	3.7	0.4	0.9	5.7	4.9	2.3	1.7
PO_4-P (kg N ha^{-1} depth)	13	17	7	9	21	30	12	12
Biomass C (kg N ha^{-1} depth)	151	350	112	369	360	413	498	791
Biomass N (kg N ha^{-1} depth)	10	34	9	30	24	41	38	34
Anaerobic NH_4-N (kg N ha^{-1} depth)	14	63	5	33	23	40	14	32
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	1.6	6.8	1.3	4.0	0.6	1.8	0.9	1.3
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	1.4	4.8	0.9	3.2	0.5	1.4	0.4	0.9

*Direct comparison of bulk density under fallow and CRP conditions is not possible because the fallow areas were rototilled before soil sample collection.

†Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

spectively. Soil quality values occurring soon after initial tillage are not included. It was felt that meaningful comparisons between fallow and CRP conditions were not possible for a fallow period lasting only a few days.

Since bulk density is an important soil quality parameter, it is listed in Tables 1, 2, and 3. However, direct comparison of bulk density values under fallow and CRP conditions is not possible because bulk density measurements were obtained following tillage on the fallow plots. In the short term, tillage usually reduces bulk density due to the creation of macropores. These newly created pore spaces are initially unstable, but become consolidated over time.

It is apparent from Tables 1, 2, and 3 that substantial differences in selected soil quality parameters existed between fallow and CRP conditions for both sampling dates. Analyses of variance were performed to determine if the differences were statistically significant. The effects of time, treatment, and time by treatment interactions on soil quality measurements at the 0–7.6 cm and 0–30.5 cm depths are shown in Tables 4 and 5, respectively.

Although the response to individual soil quality indicators varied between soils, tillage caused significant differences in several soil quality measurements obtained at both sampling depths. Tillage and fallow significantly influenced ($p \leq 0.05$) the following soil quality indicators measured at the 0–7.6 cm sampling interval on each of the three soils: total C, organic C, total N, NO_3-N, biomass C, biomass N, lab respiration 0–10 days, and lab respiration 10–20 days (Tables 1, 2, 3, and 4). Tillage and fallow also caused significant differences in the following soil quality indicators measured at the 0–30.5 cm depth on at least two of the soils: EC, organic C, total N, NO_3-N, biomass C, lab respiration 0–10 days and lab respiration 10–20 days (Tables 1, 2, 3, and 5).

Time of measurement significantly influenced NH_4-N readings at both sampling depths on at least two of the soils (Tables 4 and 5). At the 0–30.5 cm depth, EC and NO_3-N concentrations on each of the soils were also affected by time of measurement. A time by treatment interaction influenced NO_3-N concentration of each of the soils at the 0–30.5 cm sampling depth.

Soil quality measurements under tillage and fallow conditions for selected dates at the 0–7.6 cm and 0–30.5 cm depth of the Grenada, Hersh, and Pierre soils are shown in Tables 6, 7, and 8, respectively.

Table 2. Soil quality measurements under tillage and fallow, and undisturbed CRP conditions for selected dates at the 0-7.6 and 0–30.5 cm depth of the Hersh soil.

Soil Quality Indicator	0–7.6 cm Days Following Initial Tillage				0–30.5 cm Days Following Initial Tillage			
	Fallow 357	CRP 357	Fallow 665	CRP 665	Fallow 357	CRP 357	Fallow 665	CRP 665
Bulk Density* (g cm^{-1})	1.28	1.60	1.35	1.50	1.46	1.63	1.66	1.65
EC (dS m^{-1})	0.03	0.03	0.02	0.03	0.08	0.03	0.02	0.02
pH	5.8	6.0	6.0	6.0	5.5	5.8	6.1	6.1
Total C (kg C ha^{-1} depth)	4620	6210	3640	5640	23800	18600	19000	17300
Organic C (kg C ha^{-1} depth)	4620	6210	3640	5640	23800	18600	19000	17300
Total N (kg N ha^{-1} depth)	490	563	460	590	2350	1980	2420	2180
NO_3-N (kg N ha^{-1} depth)	6.3	0.4	0.7	0.6	26	1.0	4.8	0.9
NH_4-N (kg N ha^{-1} depth)	1.0	0.8	0.5	1.4	5.5	4.3	0.6	2.1
PO_4-P (kg P ha^{-1} depth)	13	15	11	12	44	39	40	35
Biomass C (kg N ha^{-1} depth)	96	124	47	79	300	320	87	300
Biomass N (kg N ha^{-1} depth)	5	20	5	15	32	50	19	29
Anaerobic NH_4-N (kg N ha^{-1} depth)	7	22	7	24	30	35	27	42
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	1.5	3.6	1.3	2.7	1.2	1.3	0.8	1.3
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	1.2	3.1	1.3	2.5	1.0	1.0	0.8	1.2

* Direct comparison of bulk density under fallow and CRP conditions is not possible because the fallow areas were rototilled before soil sample collection.

† Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

To provide useful baseline information, the initial fallow period on the Hersh, Grenada, and Pierre soils lasted only 2, 4, and 6 days, respectively. For each of the three soils and both sampling depths, significant differences in selected soil quality indicators were found between the first and second sampling dates. At the 0–7.6

Table 3. Soil quality measurements under tillage and fallow, and undisturbed CRP conditions for selected dates at the 0-7.6 and 0–30.5 cm depth of the Pierre soil.

Soil Quality Indicator	0–7.6 cm Days Following Initial Tillage				0–30.5 cm Days Following Initial Tillage			
	Fallow 335	CRP 335	Fallow 664	CRP 664	Fallow 335	CRP 335	Fallow 664	CRP 664
Bulk Density* (g cm^{-1})	0.90	0.89	0.90	1.09	0.95	1.07	1.38	1.17
EC (dS m^{-1})	0.09	0.14	0.10	0.06	0.09	0.06	0.17	0.10
pH	7.5	7.5	7.1	7.1	7.8	7.9	7.5	7.5
Total C (kg C ha^{-1} depth)†	9280	11000	9080	11800	35800	41000	48000	44800
Organic C (kg C ha^{-1} depth)	9210	10870	9040	11700	31800	38500	42900	41400
Total N (kg N ha^{-1} depth)	1100	1220	1030	1290	4130	4760	5560	5080
NO_3-N (kg N ha^{-1} depth)	6.5	0.6	4.3	0.8	21	2.3	62	3.4
NH_4-N (kg N ha^{-1} depth)	0.6	0.4	0.2	0.2	10	5.9	2.5	4.0
PO_4-P (kg P ha^{-1} depth)	5	5	3	3	10	11	10	8
Biomass C (kg N ha^{-1} depth)	341	563	312	624	867	1410	1320	1450
Biomass N (kg N ha^{-1} depth)	35	41	38	57	96	103	130	120
Anaerobic NH_4-N (kg N ha^{-1} depth)	23	31	20	41	45	76	48	64
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	2.0	4.2	2.5	6.2	1.5	2.4	1.2	2.7
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	1.5	3.1	2.3	4.3	1.0	1.6	1.0	2.1

*Direct comparison of bulk density under fallow and CRP conditions is not possible because the fallow areas were rototilled before soil sample collection.

†Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

cm depth, significant differences in all of the soil quality indicators except pH were found on at least two of the soils. Significant differences in all but the following soil quality measurements were found at the 0–30.5 cm depth on at least two of the soils: bulk density, pH, NH_4-N, PO_4-P, and biomass N.

Variations in selected soil quality indicators were also found between the second and third sampling dates at both the 0–7.6 cm and 0–30.5 cm sampling depths. At the 0–7.6 cm depth, significant differences ($p \leq 0.05$) in EC, NH_4-N, and PO_4-P were identified on at least two of the soils. Significant differences in the following soil quality indicators were also found at the 0–30.5 cm depth: EC, pH, total C, organic C, NO_3-N, NH_4-N, biomass-N, and lab respiration 0–10 days.

Discussion

Measurements of total and organic C were identical on the Grenada and Hersh soils for each sampling date and depth (Tables 6 and 7, respectively). However, values on the Pierre soil (Table 8) for organic C were always less than total C and soil pH values were above 7, indicating the presence of carbonates in the Pierre soil.

When compared to undisturbed CRP, organic C and biomass C levels at the 0–7.6 cm depth were reduced significantly by tillage and fallow on each of the three soils (Table 4). Reicosky et al. (1995) also noted a rapid increase in CO_2 suggesting a reduction in soil organic matter near the soil surface following tillage of a former no-till area in Georgia planted to sorghum.

On the Grenada soil, greater amounts of NH_4-N and anaerobic NH4-N were found at the 0–7.6 cm depth four days following initial tillage than were measured at the 0–30.5 cm depth (Table 6). The reason for this discrepancy is not known.

As a result of tillage and fallow, EC of the Grenada soil increased significantly at

Table 4. Analysis of variance for soil quality measurements under tillage and fallow, and undisturbed CRP conditions at the 0-7.6 cm depth.

Soil Quality Indicator	Grenada			Soil Hersh			Pierre		
	Time	Treatment*	Time X Treatment	Time	Treatment*	Time X Treatment	Time	Treatment*	Time X Treatment
					P R > F				
Bulk Density (g cm^{-1})	0.05	0.01	0.15	0.87	0.06	0.15	0.02	0.07	0.02
EC (dS m^{-1})	0.07	0.01	0.03	0.16	0.68	0.16	0.10	0.51	0.06
pH	0.62	0.03	0.96	0.58	0.29	0.31	0.01	0.52	0.87
Total C (kg C ha^{-1} depth)†	0.04	0.02	0.38	0.28	0.01	0.76	0.37	0.01	0.17
Organic C (kg C ha^{-1} depth)	0.04	0.02	0.38	0.28	0.01	0.76	0.32	0.01	0.15
Total N (kg N ha^{-1} depth)	0.01	0.01	0.19	0.93	0.01	0.60	0.99	0.01	0.03
NO_3-N (kg N ha^{-1} depth)	0.20	0.01	0.20	0.01	0.01	0.01	0.44	0.01	0.35
NH_4-N (kg N ha^{-1} depth)	0.01	0.14	0.57	0.86	0.23	0.12	0.01	0.54	0.06
PO_4-P (kg P ha^{-1} depth)	0.01	0.31	0.70	0.41	0.26	0.89	0.01	0.10	0.52
Biomass C (kg N ha^{-1} depth)	0.90	0.01	0.73	0.08	0.04	0.93	0.51	0.01	0.11
Biomass N (kg N ha^{-1} depth)	0.65	0.01	0.77	0.31	0.01	0.25	0.03	0.01	0.09
Anaerobic NH_4-N (kg N ha^{-1} depth)	0.08	0.01	0.30	0.66	0.01	0.77	0.61	0.08	0.34
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	0.29	0.01	0.38	0.09	0.01	0.24	0.01	0.01	0.03
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	0.10	0.01	0.33	0.20	0.01	0.16	0.01	0.01	0.34

* Treatment includes tillage, fallow, and undisturbed CRP condition. Tables 1, 2, and 3 show sampling times.
† Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

both sampling depths (Tables 1, 4 and 5). In contrast, pH of the Grenada soil was significantly less. The reduction in soil pH on this site could negatively impact the efficiency of nutrient cycling.

A substantial reduction in PO_4-P occurred on the Grenada soil during the fallow period (Table 6) for both soil sampling increments. Because of the relatively large silt and clay content of this soil, the reduction in extractable P is unlikely to be related to leaching of P due to rainfall. A more likely explanation is that tillage mineralized P by stimulating the microbial community and this showed up as Bray-1 extractable P. Over time, the mineralized P was refixed on the fallow plots. Thus, P may still be present but not in the extractable form.

Tillage and fallow caused a significant increase in NO_3-N on each of the three soils, for both sampling depths (Tables 1, 2, 3, 4, and 5). Higher soil NO_3-N often occurs when organic residues have been mineralized and nitrified but the resulting NO_3-N has not been taken up by plants. As a result of fallowing, nutrients were neither efficiently utilized nor recycled to soil organic matter by plants. Plant growth not only removes nutrients from soil resulting in reduced soil NO_3–N and PO_4–P levels, but also helps to maintain soil biological reserves of C and N. Vegetation may also reduce the potential for N leaching, and neutralize the acidity produced during the nitrification of N mineralized from organic residues.

Gilley and Doran (1998) used a rainfall simulator to measure the soil erosion potential of the three study sites at approximately the same times the samples for soil quality analyses were collected. Soil loss increased substantially during the extended fallow period on each of the three sites. Greater soil erosion could contribute to a reduction in organic carbon.

The experimental procedures used in this study allowed soil quality parameters to be measured on fallow areas for a peri-

Table 5. Analysis of variance for soil quality measurements under tillage and fallow, and undisturbed CRP conditions at the 0-30.5 cm depth.

Soil Quality Indicator	Grenada			Hersh (Soil)			Pierre		
	Time	Treatment*	Time X Treatment	Time	Treatment*	Time X Treatment	Time	Treatment*	Time X Treatment
					P R > F				
Bulk Density (g cm^{-1})	0.83	0.20	0.38	0.04	0.14	0.06	0.01	0.40	0.06
EC (dS m^{-1})	0.02	0.01	0.49	0.03	0.12	0.12	0.02	0.01	0.21
pH	0.47	0.01	0.14	0.01	0.26	0.18	0.01	0.25	0.58
Total C (kg C ha^{-1} depth)†	0.70	0.11	0.40	0.06	0.01	0.21	0.06	0.48	0.23
Organic C (kg C ha^{-1} depth)	0.70	0.11	0.40	0.06	0.01	0.21	0.03	0.02	0.13
Total N (kg N ha^{-1} depth)	0.29	0.23	0.41	0.42	0.02	0.69	0.01	0.01	0.01
NO_3-N (kg N ha^{-1} depth)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NH_4-N (kg N ha^{-1} depth)	0.03	0.29	0.87	0.01	0.80	0.01	0.06	0.52	0.19
PO_4-P (kg P ha^{-1} depth)	0.01	0.15	0.23	0.27	0.02	0.99	0.09	0.91	0.06
Biomass C (kg N ha^{-1} depth)	0.01	0.03	0.05	0.10	0.06	0.16	0.08	0.01	0.13
Biomass N (kg N ha^{-1} depth)	0.50	0.41	0.07	0.03	0.12	0.48	0.08	0.98	0.52
Anaerobic NH_4-N (kg N ha^{-1} depth)	0.26	0.06	0.94	0.48	0.14	0.12	0.52	0.03	0.26
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	0.87	0.01	0.02	0.05	0.06	0.03	0.89	0.01	0.06
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	0.15	0.01	0.32	0.59	0.20	0.06	0.28	0.02	0.22

* Treatment includes tillage, fallow, and undisturbed CRP condition. Tables 1, 2, and 3 show sampling times.
† Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

Table 6. Soil quality measurements under tillage and fallow conditions for selected dates at the 0-7.6 and 0-30.5 cm depth of the Grenada soil.

Soil Quality Indicator	0–7.6 cm Days Following Initial Tillage 4	275	632	LSD 0.05	0–30.5 cm Days Following Initial Tillage 4	275	632	LSD 0.05
Bulk Density (g cm^{-1})	1.33	1.23	0.96	0.23	1.44	1.55	1.51	0.13
EC (dS m^{-1})	0.03	0.22	0.13	0.07	0.01	0.07	0.09	0.03
pH	5.5	4.8	4.8	0.4	4.9	4 .8	4.6	0.2
Total C (kg C ha^{-1} depth)†	14000	10000	7300	2000	31800	22200	23400	4300
Organic C (kg C ha^{-1} depth)	14000	10000	7300	2000	31800	22200	23400	4300
Total N (kg N ha^{-1} depth)	1470	1130	830	170	3950	3290	3230	390
NO_3-N (kg N ha^{-1} depth)	0.1	25	31	9.1	0.3	38	67	18.3
NH_4-N (kg N ha^{-1} depth)	4.3	2.7	0.4	2.0	3.8	5.7	2.3	2.5
PO_4-P (kg P ha^{-1} depth)	22	13	7	6	33	21	12	10
Biomass C (kg N ha^{-1} depth)	264	151	112	92	604	360	498	146
Biomass N (kg N ha^{-1} depth)	33	10	9	18	46	24	38	10
Anaerobic NH_4-N (kg N ha^{-1} depth)	61	14	5	12	43	23	14	15
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	5.6	1.6	1.3	1.4	2.2	0.6	0.9	0.4
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	4.2	1.4	0.9	0.6	1.5	0.5	0.4	0.3

† Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

od of 21 or 22 months. An extended fallow period was used to identify potential changes in soil quality indicators under an extreme situation. Former CRP areas which are converted to cropland would probably remain in a fallow condition for only a few months. Once crops become established, changes in soil quality characteristics of former CRP areas would be expected to be much less pronounced than those identified in this study.

Several management options exist for converting former CRP areas to cropland. Many of the conservation and soil quality benefits derived from the CRP were found to rapidly decline once the study areas were tilled and then left fallow. Minimum-till or no-till management systems that maintain residue materials on the soil surface may be well suited for former CRP areas which are used as cropland.

Lindstrom et al. (1998) found no-till management preserved beneficial soil characteristics developed under sod culture in South Dakota into the fourth cropping year. From a production standpoint, Laryea and Unger (1995) found a no-till system to be well suited for converting revegetated land to cropland in locations where soil water is limiting. A no-till management system was also shown effective in reducing erosion potential and soil quality degradation of a former CRP area in southwest Iowa that was returned to production of corn and soybeans [*Glycine max* (L) Merr] (Gilley et al. 1997b).

Conclusion

The organic C content of rangeland soils has been reduced substantially as a result of long term cultivation. The greatest rate of change in organic C occurs the first few years following initial tillage. This study was conducted to measure changes in selected soil quality characteristics of former CRP sites in Mississippi, Nebraska, and South Dakota under extreme tillage and fallow conditions lasting for 21 or 22 months.

When compared to undisturbed CRP, organic C and total N levels at the 0–7.6 cm depth were reduced significantly by tillage and fallow on each of the three soils. Results suggest that organic residues were undergoing mineralization and nitrification throughout the fallow period. Consequently, NO_3-N values on the tillage and fallow plots increased and organic C and total N measurements at the 0–7.6 cm depth significantly decreased on each of the sites throughout the study.

Tillage and fallow may help to reduce excessive vegetation. However, many of the soil quality benefits derived during the CRP were found to rapidly decline throughout the fallow period. Such management practices as minimum-till or no-till, which maintain crop residue on the soil surface, may be best suited for reducing soil quality degradation on former CRP areas.

Table 7. Soil quality measurements under tillage and fallow conditions for selected dates at the 0-7.6 and 0-30.5 cm depth of the Hersh soil.

Soil Quality Indicator	0–7.6 cm Days Following Initial Tillage 2	357	665	LSD 0.05	0–30.5 cm Days Following Initial Tillage 2	357	665	LSD 0.05
Bulk Density (g cm^{-1})	1.72	1.28	1.35	0.24	1.50	1.46	1.66	0.16
EC (dS m^{-1})	0.00	0.03	0.02	0.01	0.00	0.08	0.02	0.05
pH	5.8	5.8	6.0	0.5	5.7	5.5	6.1	0.3
Total C (kg C ha^{-1} depth)†	3520	4620	3640	1450	18900	23800	19000	4500
Organic C (kg C ha^{-1} depth)	3520	4620	3640	1450	18900	23800	19000	4500
Total N (kg N ha^{-1} depth)	330	490	460	150	1680	2350	2420	610
NO_3-N (kg N ha^{-1} depth)	0.3	6.3	0.7	2.0	1.5	26	4.8	8.7
NH_4-N (kg N ha^{-1} depth)	0.2	1.0	0.5	0.8	1.2	5.5	0.6	1.6
PO_4-P (kg P ha^{-1} depth)	10	13	11	3	42	44	40	10
Biomass C (kg N ha^{-1} depth)	225	96	47	39	778	300	87	214
Biomass N (kg N ha^{-1} depth)	10	5	5	2	24	32	19	19
Anaerobic NH_4-N (kg N ha^{-1} depth)	13	7	7	2	62	30	27	3
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	0.6	1.5	1.3	0.7	1.8	1.2	0.8	0.3
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	0.5	1.2	1.3	0.4	1.9	1.0	0.8	0.2

† Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

Table 8. Soil quality measurements under tillage and fallow conditions for selected dates at the 0-7.6 and 0-30.5 cm depth of the Pierre soil.

Soil Quality Indicator	0–7.6 cm Days Following Initial Tillage 6	335	664	LSD 0.05	0–30.5 cm Days Following Initial Tillage 6	335	664	LSD 0.05
Bulk Density (g cm^{-1})	1.51	0.90	0.90	0.10	.37	0.95	1.38	0.20
EC (dS m^{-1})	0.17	0.09	0.10	0.06	0.20	0.09	0.17	0.05
pH	7.5	7.5	7.1	0.1	7.4	7.8	7.5	0.2
Total C (kg C ha^{-1} depth)†	14300	9280	9080	1100	51700	35800	48000	10900
Organic C (kg C ha^{-1} depth)	11700	9210	9040	1060	46100	31800	42900	7700
Total N (kg N ha^{-1} depth)	1240	1100	1030	100	4560	4130	5560	530
NO_3-N (kg N ha^{-1} depth)	0.7	6.5	4.3	5.0	2.5	21	62	22
NH_4-N (kg N ha^{-1} depth)	1.2	0.6	0.2	0.2	3.9	10	2.5	7.5
PO_4-P (kg P ha^{-1} depth)	1	5	3	1	4	10	10	2
Biomass C (kg N ha^{-1} depth)	210	341	312	92	744	867	1320	393
Biomass N (kg N ha^{-1} depth)	16	35	38	7	78	96	130	28
Anaerobic NH_4-N (kg N ha^{-1} depth)	12	23	20	23	56	45	48	26
Lab Respiration 0–10 days (kg C ha^{-1} 2.25 cm depth day^{-1})	1.6	2.0	2.5	0.7	4.3	1.5	1.2	0.2
Lab Respiration 0–20 days (kg C ha^{-1} 2.25 cm depth day^{-1})	2.0	1.5	2.3	0.7	5.7	1.0	1.0	0.2

† Metric to English unit conversion: 2.54 cm = 1.00 in; 1.12 kg ha^{-1} = 1.00 lb ac^{-1}.

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